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SOME POLICY IMPLICATIONS OF SPATIAL VARIATIONS IN FUEL CONSUMPTION BY MANUFACTURING ACTIVITIES

Introduction

Fuel consumption for heat and power by manufacturing activities varies widely from state to state relative to consumption of other inputs. For example, manufacturing activities in Massachusetts consumed 67,681 kilowatt hours of fuel per employee in 1971, whereas manufacturing activities in Louisiana consumed 1,131,692 kilowatt hours per employee or approximately twenty times as much. Looking at the phenomenon somewhat differently, manufacturing activities in Texas would have used 99.2 billion kilowatt hours in 1971 instead of the actual 534.4 billion kilowatt hours, if they had consumed at the national average of kilowatt hours per employee. (See the appendix for a discussion of the data and terms used in this study.)

If these variations are due to differences in technological practices, they imply that considerable quantities of fuel can be saved by the adoption of currently available, less energy intensive practices by firms now using more intensive practices. On the other hand, if these variations are due simply to differences in the energy required for the production of different goods, i.e. different product mixes among states, then fuel consumption can be reduced only by changing patterns of consumption or implementing new technologies.

In this paper, variations in fuel consumption by state are divided into two components, those due to varying technological practices and those due to varying product mixes. Variations in technological practices are shown to be sizable, indicating that significant fuel savings are possible from the diffusion of less intensive, on-line practices. Next the potential for success of price and tax policies to encourage such diffusion is assessed by examining the relationships between levels of oil consumption

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and prices of various fuels. Variations in oil consumption are found to be sensitive to price differences, but, as expected, industries vary both in their degrees of price sensitivity and as to the identity of the substitute fuels.

Variations in Fuel Consumption Controlling for Product Mix

Fuel consumption in kilowatt hours by two-digit, Standard Industrial Code (SIC) manufacturing industries in 1971 was disaggregated using the following formula:

Fuel consumption = $e_{ij}E_{ij}$ =

$$e_{..}\,E_{ij} + (e_{i.} - e_{..})\,E_{ij} + (e_{ij} - e_{i.})\,E_{ij},$$

where i symbolizes the ith manufacturing industry, j symbolizes the jth state, e symbolizes the ratio of fuel consumption to employment, E symbolizes employment, and · symbolizes summation across industries or across states. If the three terms on the left side of the equation are added together $e_{i.}$ and $e_{..}$ are cancelled out, leaving only $e_{ij}\ E_{ij}$, which is the state's fuel consumption per employee in the ith industry multiplied by the number of employees in the industry, and is, therefore, equal to the fuel consumption by the ith industry.

Each of the three terms in the equation has a very specific meaning. The first term is the amount of fuel which would have been used had the ith industry in the state consumed at the national average rate for all industries relative to employment; the second term is the additional or lower amount of fuel which would have been used had the industry consumed at the national average rate for the ith industry rather than the national rate for all industries combined; and the third term is the additional or lower consumption because the industry in that state consumed at a higher or lower rate than that industry did in the nation as a whole. The three terms which will be referred to as the national effect, the industry mix effect, and the state effect, respectively, are analogous to similar terms in shift-and-share analysis, a method used to disaggregate variations in economic growth rates (see Dunn [1960] for a classic presentation of that technique

and Bendavid [1974] for a well-written textbook discussion). Indeed, the method used here is identical to shift-and-share analysis with fuel consumption rates used in place of economic growth rates.

When fuel consumption by each manufacturing industry is disaggregated in this fashion and then each term is summed separately across the industries in a state, the result is a set of estimates of 1) fuel consumption by manufacturing industries in the state had they consumed at the national average rate, 2) additional or less consumption relative to that benchmark because of the state's industry mix, and 3) additional or less consumption because of differences in the consumption rates of each industry in the state relative to that industry in the nation.

The magnitudes of the industry mix effects have implications for policies to allocate fuel among the states. The mix effect was calculated for each state as a percentage of consumption had it occurred at the national average rate, i.e. the sum across industries of the second term in the previous equation as a percent of the sum of the first term or simply $e_{..}E_{.j}$. For example, the estimate of 10.3% for Illinois means that Illinois on balance manufactured goods which required 10.3% more fuel consumption than an average-consumption set of goods. The percentages for each state are shown on Map 1. Positive mix effects, which were above twenty-five percent for fifteen states and above seventy-five percent for nine states, support arguments for fuel allocations which are more than proportional to total employment.[1] More generally, the high levels of some industry mix effects underscore the necessity for fuel allocation policies to consider the composition of states' outputs.

However, the state effect is of primary interest here, since the industry mix effects cannot indicate potential energy savings for the nation

[illegible]

INDUSTRY MIX EFFECT AS PERCENTAGE OF EXPECTED FUEL CONSUMPTION

as a whole, as they sum to zero across states.[2] Specifically, positive state effects are of interest here as they indicate above average energy consumption controlling for variations resulting from product mix, at least down to the two-digit level. Map 2 shows the sum of positive state effects by state as percentages of the states' actual consumption.[3] Thirty-two of the states had positive state effects in excess of ten-percent of their fuel consumption with Texas having the highest percentage, 59.64 percent. This figure implies that fuel consumption by manufacturing plants would have been reduced by 59.64 percent if all industries in Texas which consume at above national industry-specific rates had consumed at those rates. In terms of the United States as a whole, 769 billion kilowatt hours of fuel, or 23.1 percent of the fuel consumed by manufacturing industries, would have been saved.

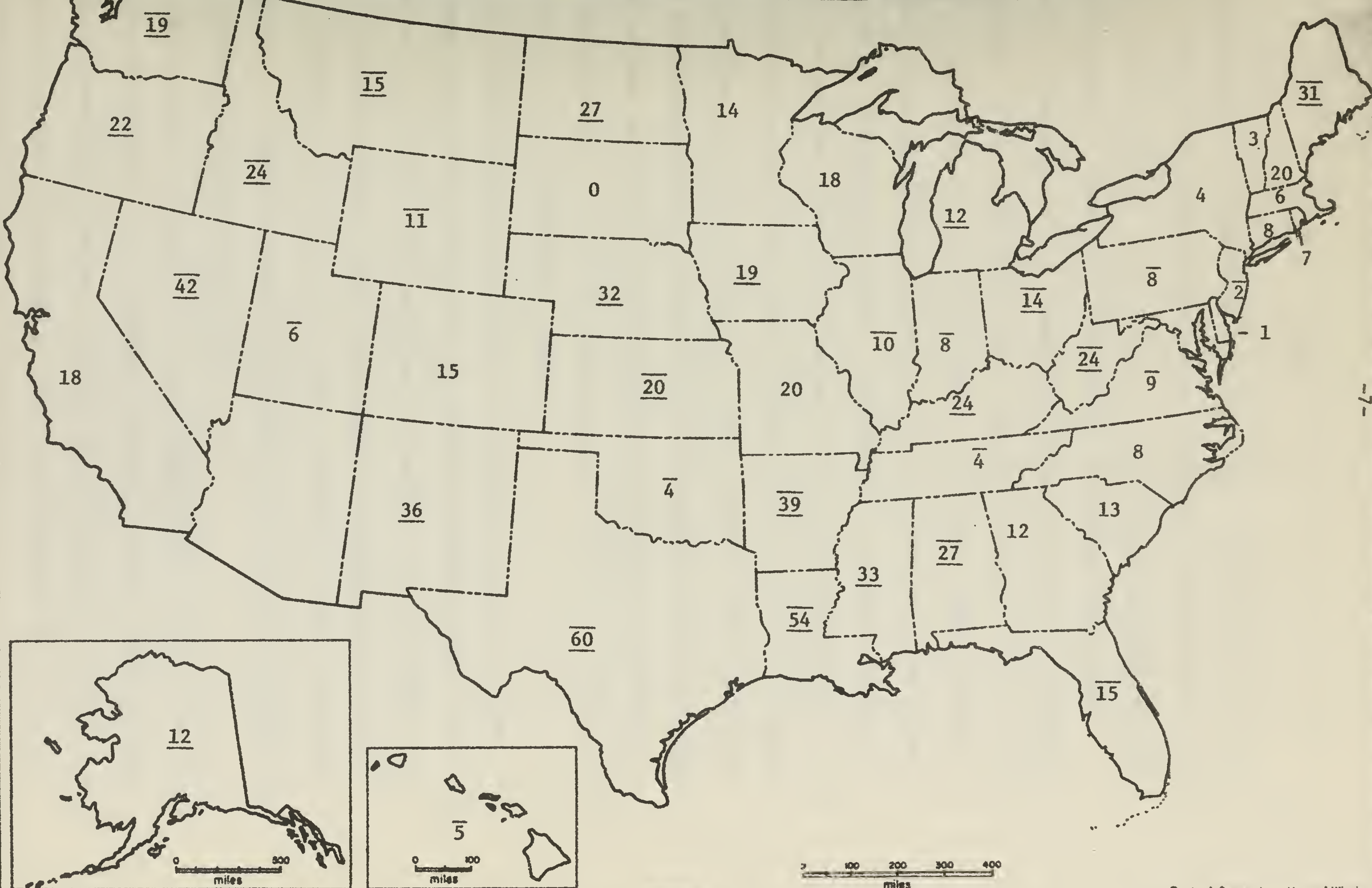
Limitations of the Estimates

The estimates of potential fuel savings presented here must be approached very cautiously for many reasons. The industry mix effect has not been separated from the state effect completely, because the latter includes variations in fuel consumption associated with different product mixes below the two-digit level. Although studies by Hewings (1972), in the context of input-output studies, and Isserman (1976), in the context of location quotient derived economic base multipliers, indicate that the greatest deleterious effects of aggregation are overcome by initial levels of disaggregation, there can be no doubt that substantial product mix effects remain in the state effects here, particularly since production technologies are at issue.[4]

The state effect has not been called the technological effect, because

POSITIVE STATE EFFECTS AS PERCENTAGE OF ACTUAL FUEL CONSUMPTION

(Overlining indicates industry-mix effect is positive and underlining indicates the state effect *in toto* is positive.)



it reflects more than technological differences. The fuel data used here do not distinguish between fuels used in production and those used in heating or air conditioning. A plant would use more energy, *ceteris paribus* if it were located in a state with more heating or cooling degree days. Therefore, variations in fuel consumption related to climatic differences are included in the state effect, too. The spatial pattern of the positive state effects shown in Map 2 indicate that the climatic effects are not dominant, since the positive effects do not form bands across the United States as do temperature isotherms. Nevertheless, an attempt should be made to control for climatically induced, technological differences.[5]

The estimates of potential fuel savings vary directly with the choice of the benchmark, average rates in this case. A more stringent benchmark based on engineering data or "best practice" information from recent input-output surveys would lead to higher estimates of potential fuel savings (see Miernyk [1965, pp. 117-127] or Miernyk *et al*., [1970, pp. 21-27] for an explanation of the best practice concept).

The estimates of fuel savings also vary with the choice of the base. Employment was used as the base for the results reported on here, but it is a poor one to the extent that employment is seasonal in a particular industry, as fuel use during the year is compared to employment in a specific week. However, an alternative base, annual income by industry, generated similar results, potential fuel savings of 22.6 percent compared to 23.1 percent with the employment base.

The fact that some product mix and climatic effects have been included in the state effects may increase the latter. Even if this were not so and the twenty-three percent level was the true measure of potential energy savings, it is not realistic to think that industries in the United

States can cut fuel consumption so drastically. Substitution of the less energy intensive practices may not be economically feasible for the private sector, at least without public subsidy. Moreover, some of this substitution may have taken place already, as a response to drastic changes in energy prices since 1971, the year of the data used here. Strictly speaking, the twenty-three percent estimate is not an upper estimate since the benchmark could have been a more stringent one. Nevertheless, the results presented here should be interpreted very conservatively. They indicate that the policy option of encouraging diffusion of more energy efficient practices may be a very fruitful one. One policy tool to affect such diffusion, namely prices, taxes, and subsidies, is examined in the next section.

The Price Sensitivity of Technological Practices

As explained in the appendix to this paper, average prices in each state for oil, coal, and natural gas were estimated utilizing data from the special 1971 survey of manufacturing industries. These prices include "freight charges and other direct charges incurred by the establishment in acquiring these fuels (U. S. Department of Commerce, 1973, p.3)." Since reducing oil consumption by the United States has become a policy objective in the wake of the recent oil embargo and subsequent price increases, the price sensitivity of oil consumption is examined here. Specifically, oil consumption per employee was regressed against the prices of oil, natural gas, and coal, as well as average wages and heating and cooling degree days. All variables are industry-specific except the degree day variables. Separate equations were estimated for each industry, but all of the fuel variables mentioned above could not be included for each industry since particular industries in some states used negligible, undisclosed amounts of certain

fuels.

Table 1 presents results for the set of variables most frequently usable, namely oil consumption as a function of oil prices, natural gas prices, wages, and degree days. To illustrate, the information shown in Table 1 for the food products industry (SIC20) indicates that a complete set of those variables was available for the food products industry in thirty-five states. Simple OLS regressions of the logarithms of all the variables revealed that only three of them were associated significantly in a statistical sense with the level of oil consumption per employee; the other variables were examined but found insignificant. Since logarithms of all variables were used in the regression, the coefficients are interpreted in percentage terms, e.g. the coefficient of 1.499 for natural gas indicates that a one percent increase higher price of natural gas is associated with a 1.499 percent higher oil to employee ratio.

Turning to the results in general, oil consumption, measured in barrels per employee, showed a significant sensitivity to oil prices in seven of the fourteen industries, with a one percent higher price of oil associated with 1.63 to 4.2 percent lower ratios of oil to employees.[6] Moreover, oil consumption was sensitive to the price of natural gas in eleven industries with a one percent higher price of natural gas associated with higher oil consumption per employee of .9 to 3.6 percent. Oil consumption was sensitive to wages in five of the industries, although in one case the sign of the relationship was the opposite of that expected, since higher wages usually are assumed to be associated with less labor intensive practices; in the four cases with the expected sign, one percent higher wages was associated with from 1.0 to 4.4 percent higher oil consumption per employee. Finally, the degree day variables were significant three times in the case of

Industry	SIC	R^2	Price (Log)	Price (Log)	Wage (Log)	Degree Days (Log)	Degree Days (Log)	Number of Observations
Food and Kindred Products	20	.37	--	1.499# (3.216)**	1.036 (1.928)*	--	- .3554 (1.530)	35
Textile Mill Products	22	.70	--	2.611 (3.687)**	2.816 (2.514)*	--	--	15
Lumber and Wood Products	24	.42	-1.639 (2.091)*	--	--	--	- .6094 (1.977)*	16
Paper and Allied Products	26	.57	-4.204 (6.071)**	--	--	--	--	30
Chemicals and Allied Products	28	.34	-3.103 (2.506)**	.924 (1.720)*	-2.096 (1.421)	--	--	34
Petroleum and Coal Products	29	.67	-3.401 (4.105)**	2.500 (3.808)**	--	--	--	15
Rubber and Plastics Products, NEC	30	.49	--	3.172 (3.010)**	--	1.571 (1.833)*	2.958 (3.005)**	20
Stone, Clay, and Glass Products	32	.48	-3.929 (4.452)**	.9778 (1.755)*	1.494 (1.731)*	--	--	32
Primary Metal Industries	33	.25	--	1.079 (1.805)*	4.396 (2.396)*	--	--	29
Fabricated Metal Products	34	.46	--	3.046 (2.793)**	--	.845 (2.934)**	--	23
Machinery, Except Electrical	35	.49	-2.629 (2.314)*	1.786 (2.772)**	--	1.417 (2.761)**	--	22
Electrical Equipment and Supplies	36	.20	--	3.600 (2.264)*	--	--	--	22
Transportation Equipment	37	.41	-2.869 (1.727)	2.628 (2.942)**	--	--	--	19
Miscellaneous Manufacturing Industries	39	.35	--	--	--	--	-1.402 (2.551)*	14

#This number is the regression coefficient, whereas the number in parentheses is its t-value. All the regression coefficients are significantly different from zero with a 90% probability, those marked by a single asterisk with a 95% probability, and those marked by a double asterisk with a 99% probability. Variables for which no coefficients and t-values are shown were not included in the particular regression shown in the table; had they been included, they would have been insignificant.

heating and four times in the case of cooling. The signs were as expected for heating degree days, but not as expected for cooling degree days in three equations. There is no readily apparent reason for more cooling degree days to be associated with less oil consumption, although the degree day data themselves do leave something to be desired (see the appendix).

When oil was divided into residual and distillate oil and the analysis was repeated, most of the results were consistent with those presented above, as can be seen in Table 2. Consumption of both types of oil was found sensitive to the price of natural gas in ten instances, all with the expected sign. Distillate oil consumption was sensitive to the price of distillate oil in three cases and to the price of residual oil in two cases, also all with the expected sign. However, there were unexpected signs in two of the four significant cases involving wages, in both cases involving heating degree days, and in three of the six cases involving the prices of residual or distillate oil in the residual oil equations. The number of cooling degree days was not significantly associated with oil consumption of either type, even though it had been for total oil consumption in the case of two industries which were included among the residual oil equations.

The analyses shown in Table 1 and Table 2 were repeated for the subset of observations for which sufficient observations on coal prices were available, namely SIC industries 20, 26, 28, 32, and 33. The coal price variable was never significantly associated at the 90 percent level with oil consumption. However, when the equations were rerun with coal consumption measured in short tons per employee as the dependent variable, the price of coal was significant.

Conclusion

The results presented in this paper, although based on crude techniques,

	SIC	R^2	Distillate Price	Residual Price	Gas Price	Wage	Heating Degree Days	Cooling Degree Days	Number of Observations
Distallate	20	.51	--	2.714# (4.232)**	.956 (2.474)**	--	--	--	30
	26	.47	-3.243 (4.633)**	--	--	--	--	--	30
	28	.20	-3.077 (2.230)*	--	--	--	-3.823 (1.356)	--	27
	29	.64	--	--	3.604 (3.779)**	--	--	--	10
	30	.51	--	--	5.010 (3.020)**	--	-1.538 (2.061)*	--	12
	32	.22	-.2.517 (2.133)*	--	--	1.633 (1.713)	--	--	23
	33	.22	--	--	.9391 (2.179)*	--	--	--	19
	34	.75	--	2.302 (2.869)**	4.593 (3.477)**	-11.021 (3.564)**	--	--	13
Residual	22	.88	-1.152 (1.690)	4.189 (2.257)*	3.177 (2.723)*	5.514 (3.444)**	--	--	13
	26	.62	--	-4.255 (5.087)**	--	--	--	--	18
	28	.27	--	-2.200 (2.468)*	2.189 (2.083)*	--	--	--	27
	33	.55	--	6.083 (2.491)*	1.271 (1.592)	--	--	--	11
	35	.37	--	--	3.493 (2.647)**	--	--	--	14
	37	.57	--	-4.637 (2.895)**	2.785 (2.221)*	-3.656 (1.492)	--	--	15

#This number is the regression coefficient, whereas the number in parentheses is its t-value. All the regression coefficients are significantly different from zero with a 90% probability, those marked by a single asterisk with a 95% probability, and those marked by a double asterisk with a 99% probability. Variables for which no coefficients and t-values are shown were not included in the particular regression shown in the table; had they been included, they would have been insignificant.

underscore the argument that demand-oriented policies to reduce fuel consumption should not be ignored for the more glamorous pursuit of new technologies and new energy sources. Further diffusion of existing, on-line technologies may offer considerable fuel savings, although that conclusion of this macroeconomic inquiry is in need of verification by engineering studies or industry surveys. The sensitivity of fuel consumption to price differences implies that pricing policies may be an effective way to affect technological practices. For example, the sensitivity of oil consumption to natural gas prices and its insensitivity to coal prices imply that a deregulation of natural gas prices will lead to an increase in oil consumption, but that subsidization of coal prices will not reduce oil consumption by manufacturing activities. However, such regression analyses are not by themselves sufficient information for policy decisions and must be verified by industry information.

NOTES

[1]Fuel allocation formulae may be based on valued-added, earnings, or other measures as well as employment. The estimates can be recalculated with any of those bases. In fact, the entire analysis reported here was conducted with earnings data from the Bureau of Economic Analysis in place of the employment data; the basic result, namely sizable industry mix effects, was unchanged.

[2]The industry mix effect for a state is

$$\sum_i (e_{i.} - e_{..})E_{ij} \text{ or}$$
$$\sum_i e_{i.}E_{ij} - \sum_i e_{..}E_{ij} \text{ or}$$
$$\sum_i e_{i.}E_{ij} - e_{..}E_{.j} \, .$$

If this effect is summed over all states, the result is

$$\sum_j (\sum_i e_{i.}E_{ij} - e_{..}E_{ij}) \text{ or}$$
$$\sum_j \sum_i e_{i.}E_{ij} - e_{..}E_{..} \text{ or}$$
$$\sum_i e_{i.}E_{i.} - e_{..}E_{..} \text{ or}$$
$$e_{..}E_{..} - e_{..}E_{..} \text{, which equals zero.}$$

See Stokes (1974) for further discussions of the mathematical properties of the components of the shift-and-share technique, each of which is analagous to a component of the method used here.

[3]The sum of the positive state effects is defined as the sum of the state effects, $(e_{ij} - e_{i.})E_{ij}$, for those industries in the state for which e_{ij} is greater than $e_{i.}$. In those industries fuel can be saved by adopting technologies which consume at the industry average rate. The state effect *in toto* may be negative, indicating on balance industries in the state consume more than their counterparts in the nation as a whole; but the state may still have positive state effects in certain industries.

[4]Although industrial mix effects below the two-digit level are included in the state effects here, it does not imply that the state effects are over-estimated. States would have smaller state effects with further disaggregation if they had relatively high shares of employment in the three-digit industries which are relatively high fuel consumers within their two-digit groups. Thus, whereas the sum of the state effects for all the states is zero at any level of aggregation, the sum of the <u>positive</u> state effects will vary with the level of aggregation, and may be higher or lower than the estimate presented here. (See Houston [1967] for further discussion of this point in the context of shift-and-share analysis.)

[5]Such an attempt is being undertaken as a continuation of the research reported on here. The state effect is being disaggregated according to the following formula:

$$(e_{ij} - e_{i.})E_{ij} = (e_{ij} - E_{ir})E_{ij} + (e_{ir} - e_{ij})E_{ij}$$

where r refers to a set of regions defined by combining states with similar climatic conditions. The first term on the left side of the equation is the technological effect, whereas the second is the climatic effect.

[6]By definition these coefficients can be called elasticities, but that term is eschewed here because of the crudeness of the estimation methods, most importantly, the use of cross-section data and average prices, the paucity of observations, and the fact that current prices are considerably different from those prevailing in 1971.

APPENDIX

The Data

The data on 1971 fuel consumption by two-digit manufacturing industry by state were collected as part of the 1972 Census of Manufactures and are found in its special report series under the title, "Fuels and Electric Energy Consumed," and the number MC72 (SR)-6. Data for oil are measured in barrels, for coal and coke in tons, and for natural gas in cubic feet. In addition to data on fuels consumed, the publication gives costs of the fuels, including freight charges and other direct charges. The price variables used in this study were constructed by dividing the quantity of fuel consumed by its costs, yielding an average, industry-specific price for each state. The kilowatt hours referred to in this paper are actually kilowatt hour equivalents formed by converting all fuel consumption to kilowatt hours. This conversion was carried out by the Census; the conversion factors it used are listed on page 4 of the above cited report.

The data on 1971 employment by two-digit manufacturing industry comes from the 1971 County Business Patterns and is a count of employees during the period that includes March 12. No distinction is made between part-time and full-time employees, and no adjustments for seasonal variations are made. To the extent that these phenomena vary from state to state, the fuel consumption per employee data used in this study are flawed. A data series without these weaknesses, namely annual income by two-digit industries by state, is referred to in this paper too. Those data are available on computer printouts from the Bureau of Economic Analysis, U. S. Department of Commerce.

The heating and cooling degree days data were constructed from maps showing isorithms of each. Parts of a state may exhibit great ranges in

degree days, e.g. Texas from less than 1500 to more than 4000 heating degree days (Portland, Maine, has approximately 1000), but for this study a number had to be estimated for each state. This was done judgementally by looking at the distribution of employment centers in the state relative to the map of isorithms. These data are very crude not only for this reason, but because the cooling degree days are for 1956 (Thom, 1957) and the heating degree days represent "normal" levels for the period 1921-1950 (U. S. Department of Commerce, 1956). It would have been possible to construct more precise series by using average temperatures at a number of weather stations in each state for each month in 1971, converting them to degree days, and weighting the levels at the various locations within states by some measure such as employment or population. However, that was not possible within the resource constraints of this study.

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